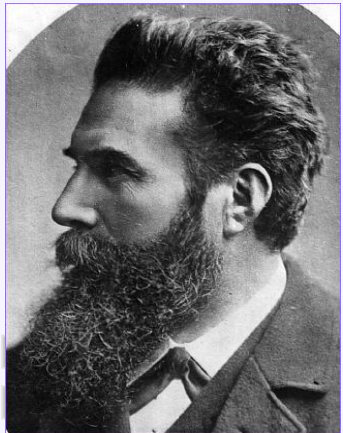
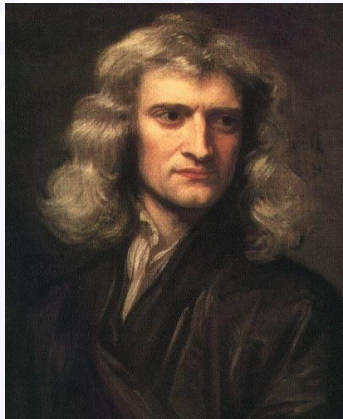




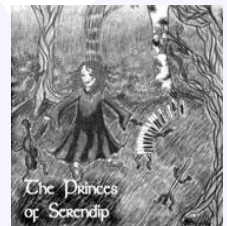
INVENTION, SERENDIPITY, and RESEARCH HYPOTHESIS with a SYSTEMS APPROACH

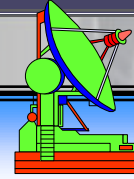


Moon Won Suh, *Ph.D.*

Charles A. Cannon Chair Professor

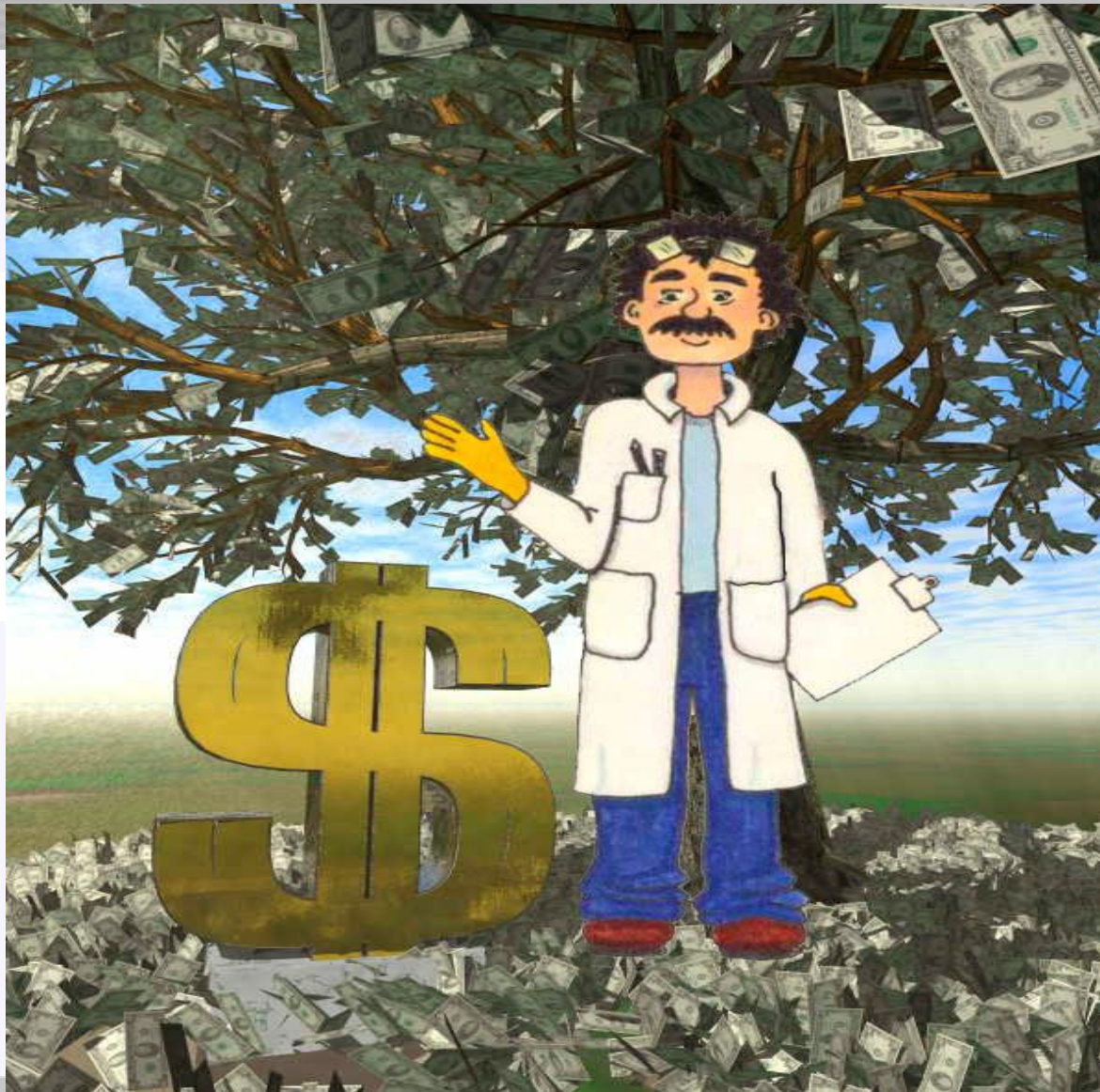
North Carolina State University





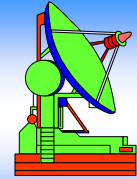
R&D in Global Competition

- **Understanding and Prediction of *Future Needs***
- **Forecasting of *Future Technologies***
- **New and Improved *Products, Processes and Services***
- **New and Improved *R&D Processes***
- **Conversion into *Sellable Products and Services***



“R&D Paradox”

– Korea Herald, June 8, 2014 Editorial



OECD Report on Korea's Invention Policies:

2012 R&D Spending = \$49.2 Billion

(6th out of 34 member countries)

(4.0% of GDP, 2nd to Israel; 4.4%)

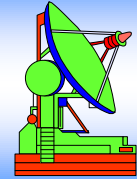
R&D Output = Low!

(1 out of 4 tech transfer to industry)

(1 out of 10 commercialization)

“R&D Paradox”

– Korea Herald, June 8, 2014 Editorial



OECD Report on Korea's Invention Policies:

Number of Scientific Publications

= 12th in the World

Number of Patent Applications

= High!

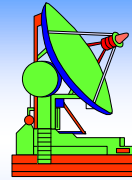
A Contributing Factor for Paradox

= Lack of Funding for Commercialization

“A Trillion-Dollar R&D Fix”

Harvard Business Review,

May 2012, by Anne Marie Knott



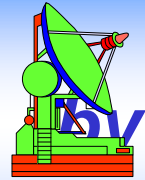
Booz & Company ***“The Global Innovation 1000” 2010 Report:***

“Spending more on R&D won’t drive results. The most crucial factors are strategic alignment and a culture that supports innovation.”

“A Trillion-Dollar R&D Fix”

Harvard Business Review May 2012,

by Anne Marie Knott



“The trouble is that it’s also hard to measure strategic alignment and culture, let alone link them to profitability or market value.”

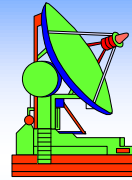
“Co. with >\$100M Revenues: ↓5.6% R&D intensity (R&D Spending/Revenue), ↓4.8% Capital Intensity, ↑3.4% Advertising.”

“RQ (Research Quotient)”

by Anne Marie Knott

<http://www.amkanalytics.com/files/tutorial.pdf>

<http://hbr.org/2012/05/the-trillion-dollar-rd-fix/ar/1>



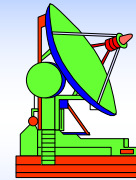
Company	RQ	R&D Spending (\$M)
Google	110	\$3,762
Apple	104	\$1,782
Biogen	110	\$1,493
GE	102	\$3,939
GM	107	\$6,962
Wolkswagen	129	\$9,110
Yahoo	106	\$1,082
Seattle Genetics	129	\$146

“RQ (Research Quotient)”

by Anne Marie Knott

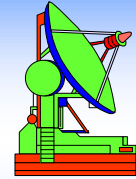
<http://www.amkanalytics.com/files/tutorial.pdf>

<http://hbr.org/2012/05/the-trillion-dollar-rd-fix/ar/1>



Company	RQ	R&D Spending (\$M)
Abbott Lab	100	\$4,037
DuPont	102	\$1,651
HP	115	\$2,959
Boeing	107	\$4,121
Caterpillar	101	\$1,905
Johnson & Johnson	102	\$6,844
Xerox	106	\$653
Unilever	102	\$1,231

***“RQ (Research Quotient)”
- a Major Issue in India***



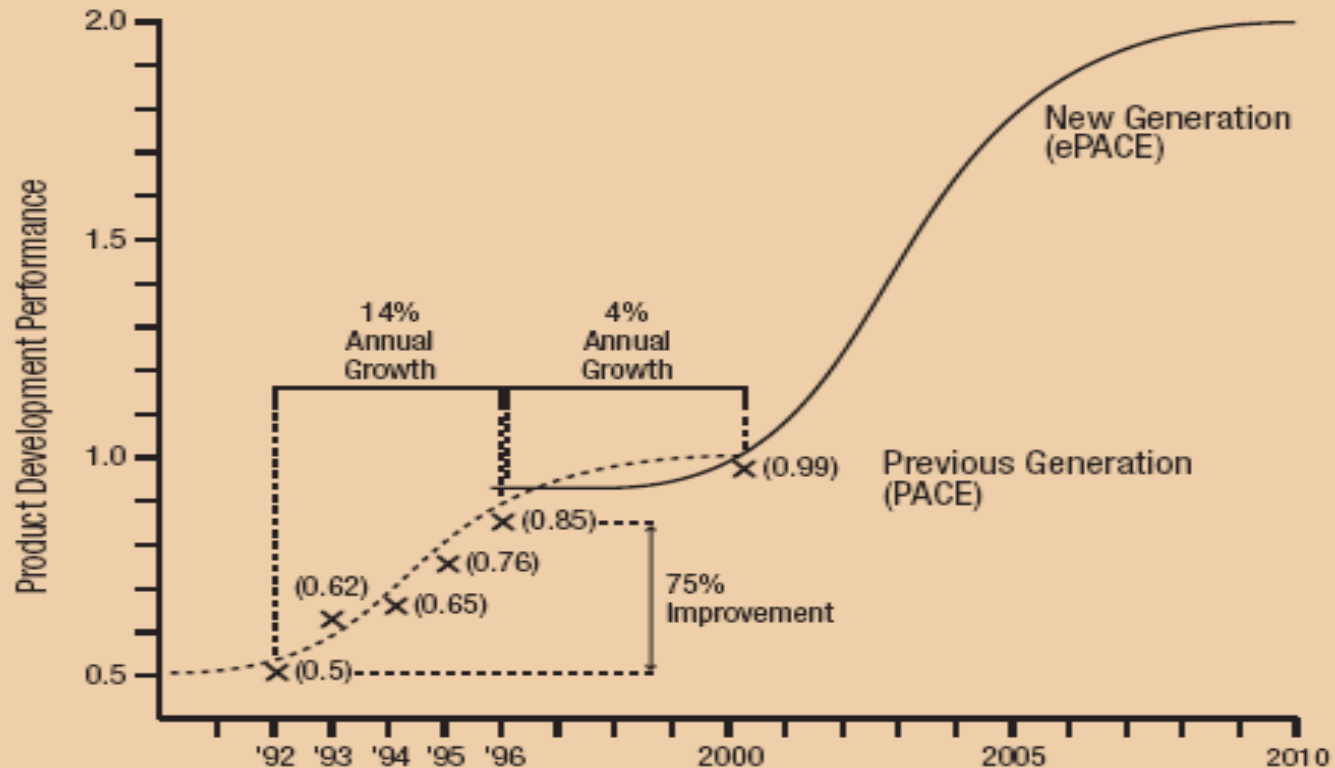
The New Indian Express, June 23, 2014

**Smitri Irani, Minister of Human
Resource Development**

“Increase RQ!” – an urgent issue

***An address to Indian Institute of
Science & Indian Institute of Science
Education***

R&D Effectiveness Index



R&D Effectiveness Index: Measures transformation of R&D spending into profits. At an Index value of 1.0, a company's investment in R&D is equal to the profit it receives from new products: the break-even point for R&D investment. An RDEI of 0.5 would mean that a company receives \$0.50 in new product profit for every dollar it spends on R&D; an RDEI of 2.0 would mean \$2 profit for every \$1 investment.

Source: Performance Measurement Group, LLC, a PRTM Company

PRODUCTIVITY ISSUE:

"In terms of actual work on knowledge worker productivity, we are, in the year 2000, roughly where we were in the year 1900, a century ago, in terms of the productivity of the manual worker."

- Peter F. Drucker

Management Challenges for the 21st Century

RESEARCH and the *TOOLS*

**Just like art, research tools
and methods are many;**

Theories (hypotheses)

Observations (data)

Experiments (empiricism)

Prediction (conjectures)



***A Systems Approach for
Validation of a Research
Hypothesis?***

PERHAPS!!

Serendipity for Invention and Discovery:

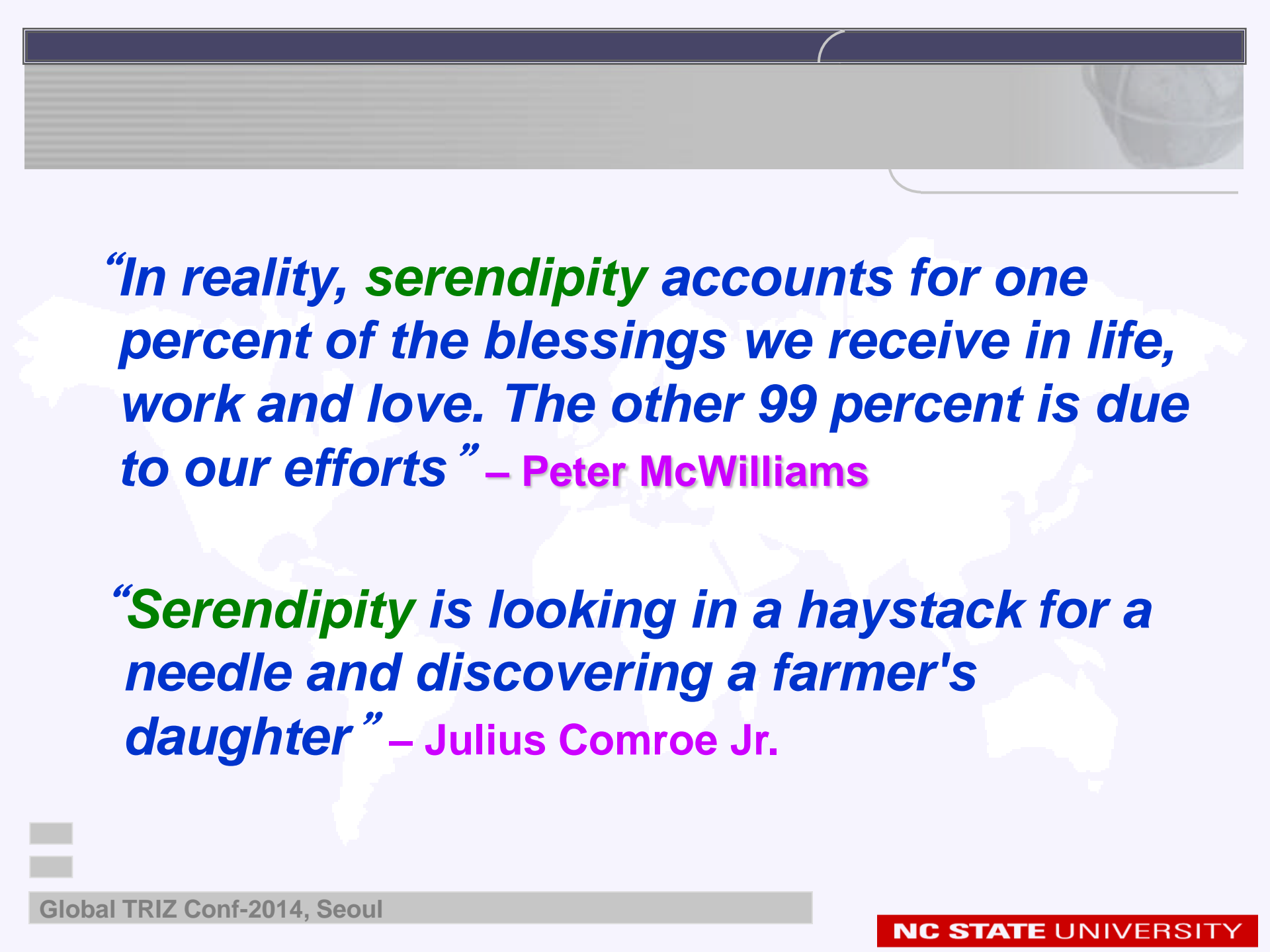
***What should one expect and
do we have to be prepared
with?***

Napier, Nancy K., and Vuong Quan Hoang. "Serendipity as a strategic advantage?." *Strategic Management in the 21st Century*
Edited by Timothy J. Wilkinson., 2013



“In the field of observation, chance favors only the prepared mind” – Louis Pasteur

“Serendipity. Look for something, find something else, and realize that what you've found is more suited to your needs than what you thought you were looking for ” - Lawrence Block

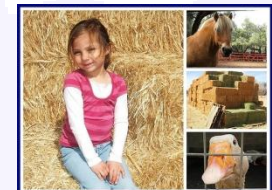


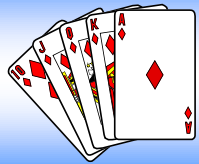
*“In reality, **serendipity** accounts for one percent of the blessings we receive in life, work and love. The other 99 percent is due to our efforts” – Peter McWilliams*

*“**Serendipity** is looking in a haystack for a needle and discovering a farmer's daughter” – Julius Comroe Jr.*

“Serendipity” - Needle in a haystack?

- Find a Farmer’s Daughter in stead!

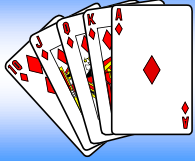




“CHANCE” and “ACCIDENTS” vs. Discovery and Invention



- 1. Are the “*Accidents*” True Accidents? - Perhaps Not!**
- 2. Conditions for Recognizing an Accident - Must know what is NOT an accident, i.e., the *knowledge base* for “normal science”**
- 3. Must Provide a *New Insight* - whether Trivial or Intuitive**



Preparation for “CHANCE” and “ACCIDENTS”



“If you are scientifically well prepared and have the openness of mind, and an opportunity arises then also you are prepared to recognize it. If you do recognize it, then other people will say you were lucky. You, within the system, will not see it as luck; you will see it an opportunity taken when you were prepared to take it.”

(Rohrer, *Organization and Scientific Discovery* by John Hurley, Wiley, New York, 1997, pp89)



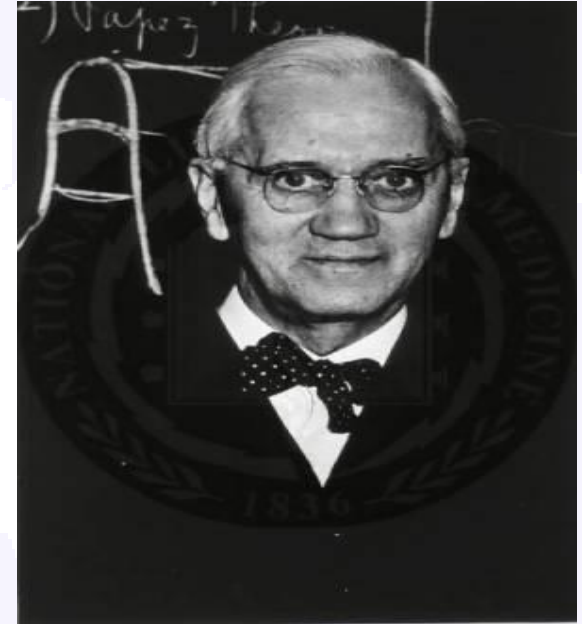
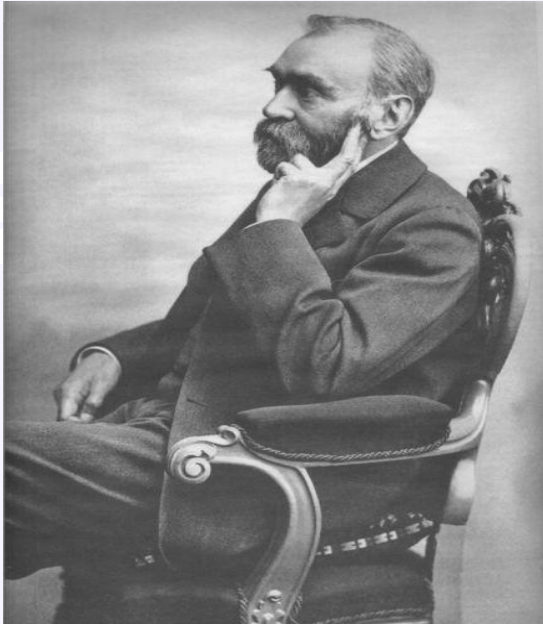
Preparation for
“CHANCE” and “ACCIDENTS”



*“Chance in the sense of something **random**, I do not believe in. I think there are a lot of things which simply come along by chance and you do not think about them. I think that is an important part of creativity, that when the unexpected things happen, you notice that this is something new. Many people said that my work with Binnig was a lot of luck. Sure it was luck but I think being lucky doesn't downgrade any achievement, because most people are lucky, and most don't notice that they are.”*

Global
(Rohrer, *Organization and Scientific Discovery*, pp88)

Serendipity in Medicine & Biology

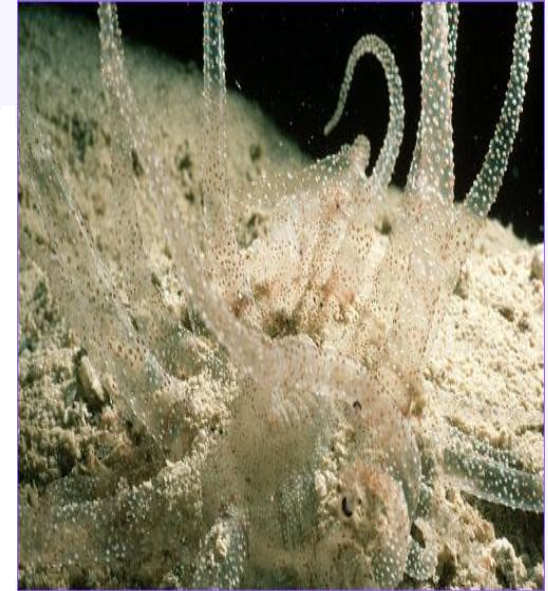


Alfred Nobel – Gelignite

Louis Pasteur – Racemization

Alexander Fleming – Penicillin

Serendipity in Medicine & Biology

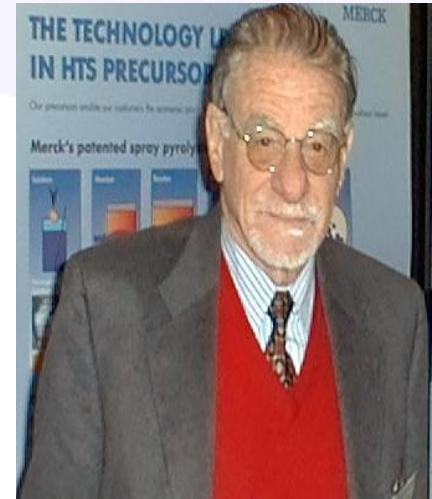
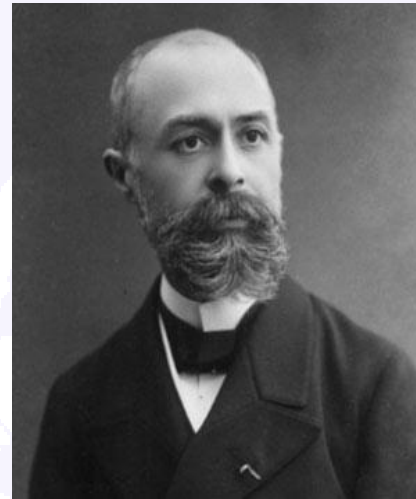


Quinine – A Christian Missionary

Smallpox vaccination - Edward Jenner

Allergy - Charles Robert Richet

Serendipity in Physics & Astronomy



S. N. Bose – Bose Einstein Statistics

William Herschel – Uranus & Infrared Radiation

Antoine Henri Becquerel – Radioactivity

**Karl Alexander Mueller – High Temperature
Superconductivity**

THE MODEL – What is It?

*All models are wrong;
only some are useful.*

<George Box>

THE GOOD MODEL?

*The **MODEL** should be based on the research hypothesis to be tested and the corresponding statistical hypothesis.*

A GOOD MODEL?

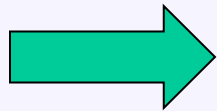
MODEL should be based on the research hypothesis to be tested and the corresponding statistical null hypothesis (rejected).

A NULL HYPOTHESIS

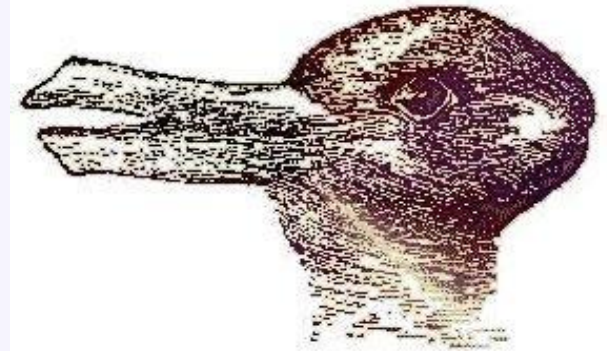
A NULL HYPOTHESIS

exists to be rejected!

To prove the research hypothesis



***NEEDED: A SYSTEMS
APPROACH FOR
VALIDATING RESEARCH
HYPOTHESIS***



EFFICIENT R&D PROCESS

Formulation of a New Problem

- A Major Component of Discovery and Inventions

“Formulation of a problem is often more important than its solution ---. To raise new questions, new possibilities, to regard old problems from a new angle, requires creative imagination and marks real advance in science.”

*(Einstein and Infeld - in *Evolution of Physics*, 1938)*

EFFICIENT R&D PROCESS

Formation of a Hypothesis

- ◇ *Imagination, Imagination!*
- ◇ *Formation of New Paradigms and New “Normal Science” must include the outliers and singletons or old exceptions*
- ◇ *Question - “Could there be more than one new alternative normal science?”*

EFFICIENT R&D PROCESS

Experimental Stage

- ◇ **Experimental Objectives**
- ◇ **Random vs. Designed Experiments**
(Probability of a Successful Proof or Validation of a Research Hypothesis)
- ◇ **Precision and Accuracy**
- ◇ **Cost/Time vs. Type I & II Errors**

EFFICIENT R&D PROCESS

Verification Stage

- ◇ **Analysis** *Loyal to the Research Hypothesis*
- ◇ **Analysis** *Specific to the Experimental Design*
- ◇ **Errors** *in the Structural Relationship*
- ◇ **Necessity Test**
- ◇ **Sufficiency Test**
- ◇ **Modification** *(if any) to a New Hypothesis*

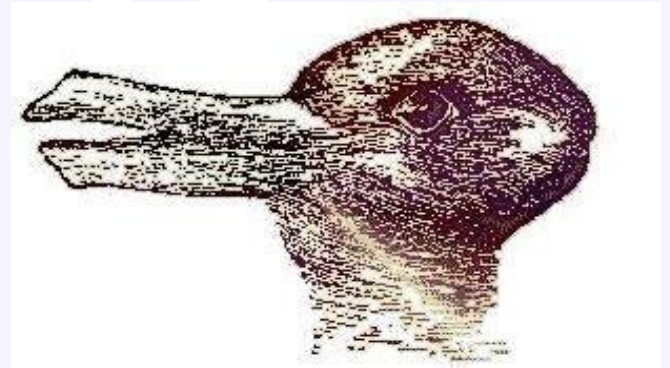
EFFICIENT R&D PROCESS

Product/Process Development

- ◇ **Recognition of *Market Potential* and *Consumer Response***
- ◇ ***Product Life Cycles* - Introduction, Growth, Maturity, Decline**
- ◇ ***Engineering Design* and Cost Factors**
- ◇ ***Evaluation and Testing***
- ◇ ***Marketing and Advertisement***

RESEARCH HYPOTHESIS

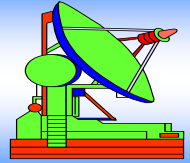
-What is it?





***NO* Research
Hypothesis
= *Beating Around the
Bush!***

Research Hypothesis



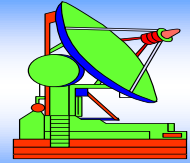
Definition:

- Prediction of a presumed relationship between one or more variables

Purpose:

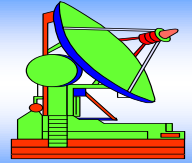
- Direct the research design
- Form a knowledge base (*Normal Science*)
- Guard against superficiality

Workable Hypothesis



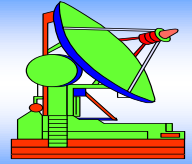
- **State the presumed hypothetical relationship**
- **Be based on a sound, justifiable rationale**
- **Be consistent with an existing body of research findings**

Developing a Hypothesis



- 1. Inductive Hypothesis:**
Based on experiences and observations
- 2. Deductive Hypothesis:**
Based on general theoretical principles

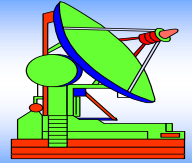
Developing a Hypothesis



Questions to be Asked:

- *How does it fit into the existing knowledge?*
- *What work has already been done that is relevant?*
- *How would you operationalize the question?*
- *What is the experimental design?*

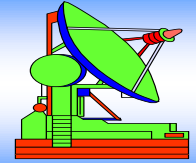
Developing a Hypothesis



Questions to be Asked:

- *What are the independent and dependent variables?*
- *Are the measures valid and reliable?*
- *Can you collect the data?*
- *What analyses will you use?*
- *Do you have enough resources?*

Developing a Hypothesis

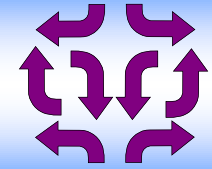


Suggested Guidelines:

- ***NO AMBIGUITY!!!!***
 - **Be specific and straightforward.**
- ***KEEP IT SIMPLE AND FOCUSED!***
 - **Don't confuse your readers.**
- ***DELIVER A REASONABLE AMOUNT OF SCIENCE!***
 - **No more, no less.**



Foundation of Good Research Hypotheses



- 1. Knowledge Base**
 - *Science, Information, Experiences*
- 2. Relevance to the Issues and Needs**
- 3. Intuition, Inspiration, Extrapolation**
- 4. Uniqueness and Completeness**
- 5. Generalization into a Wider Scheme**

The Truth #1:

“Every discovery and invention, whether significant or not, is based on serendipity and chance ! ”

- MWS

The Truth #2:

“The Expected Return from R&D is maximized by optimal selection of research projects, most suitable research hypotheses and the validation methods!” - MWS



These Tasks are Achieved by:

- 
- 1. Expert knowledge base**
 - 2. Experience with age (yes, age!)**
 - 3. Sustainable commitment**
 - 4. Environment and tradition**

Issues/Crisis #1

*The probability of a success (finding a gold mine) - **picking the methods should not be random!** Some roads are proven to lead to dead ends and/or no gold mine based on the past experience.*

*Picking the road for the trip is crucial for the maximum return. The "Question" : **How do we retain the knowledge base (experience)?***

Issues/Crisis #2

Early retirement of R&D workers
– A suicidal track? (for Japan, Korea and U.S.).

Exodus to universities and inexperienced R&D work force
- Effectiveness and sustainable R&D productivity.


Issues/Crisis #3

Practice of hiring only the "specialists" (by industry and academia) – reduction in the chance of discovery and invention via serendipity due to lack of "fusion" and interdisciplinary research.

Scientific Paradigms

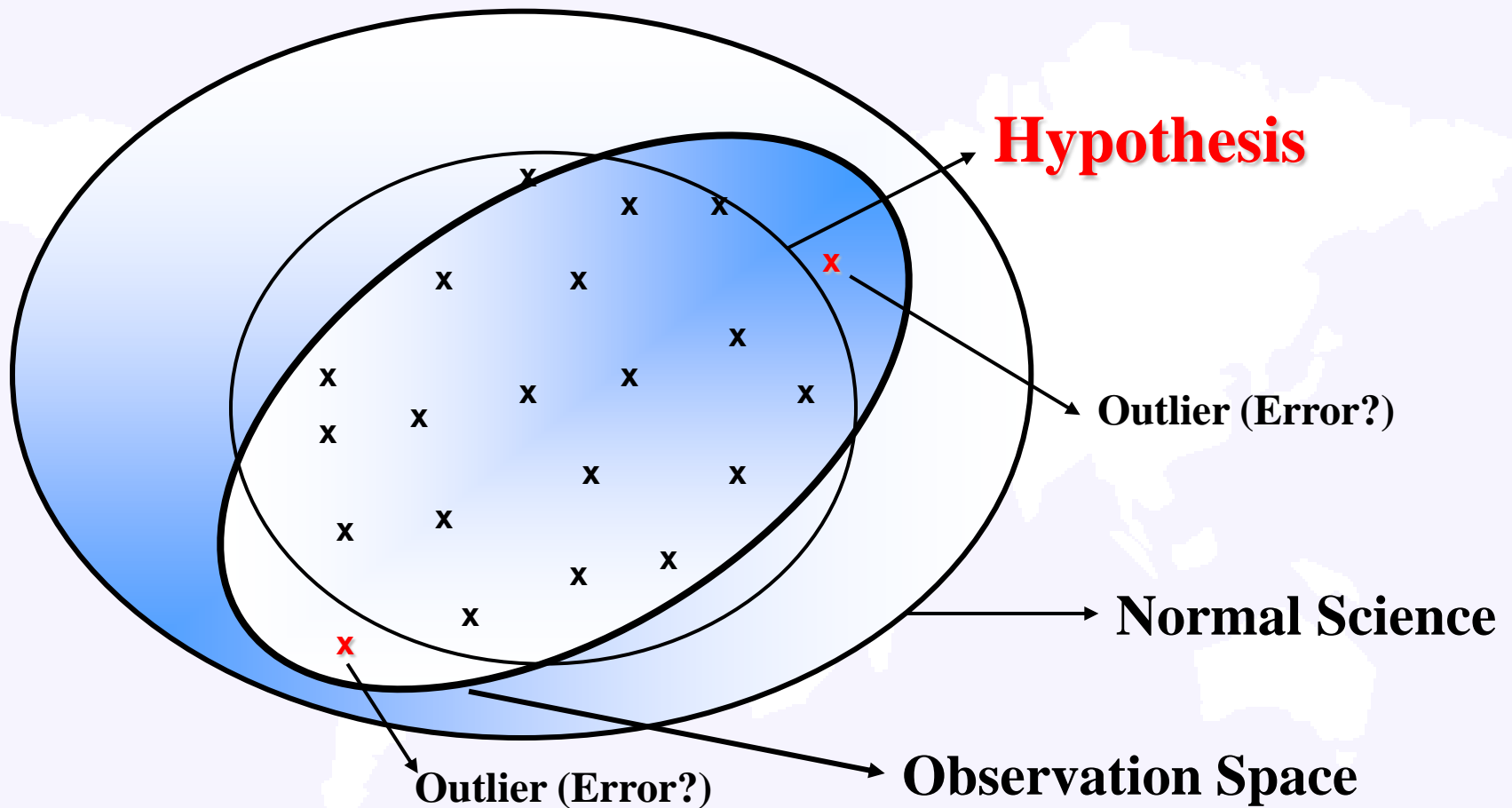
Thomas S. Kuhn:

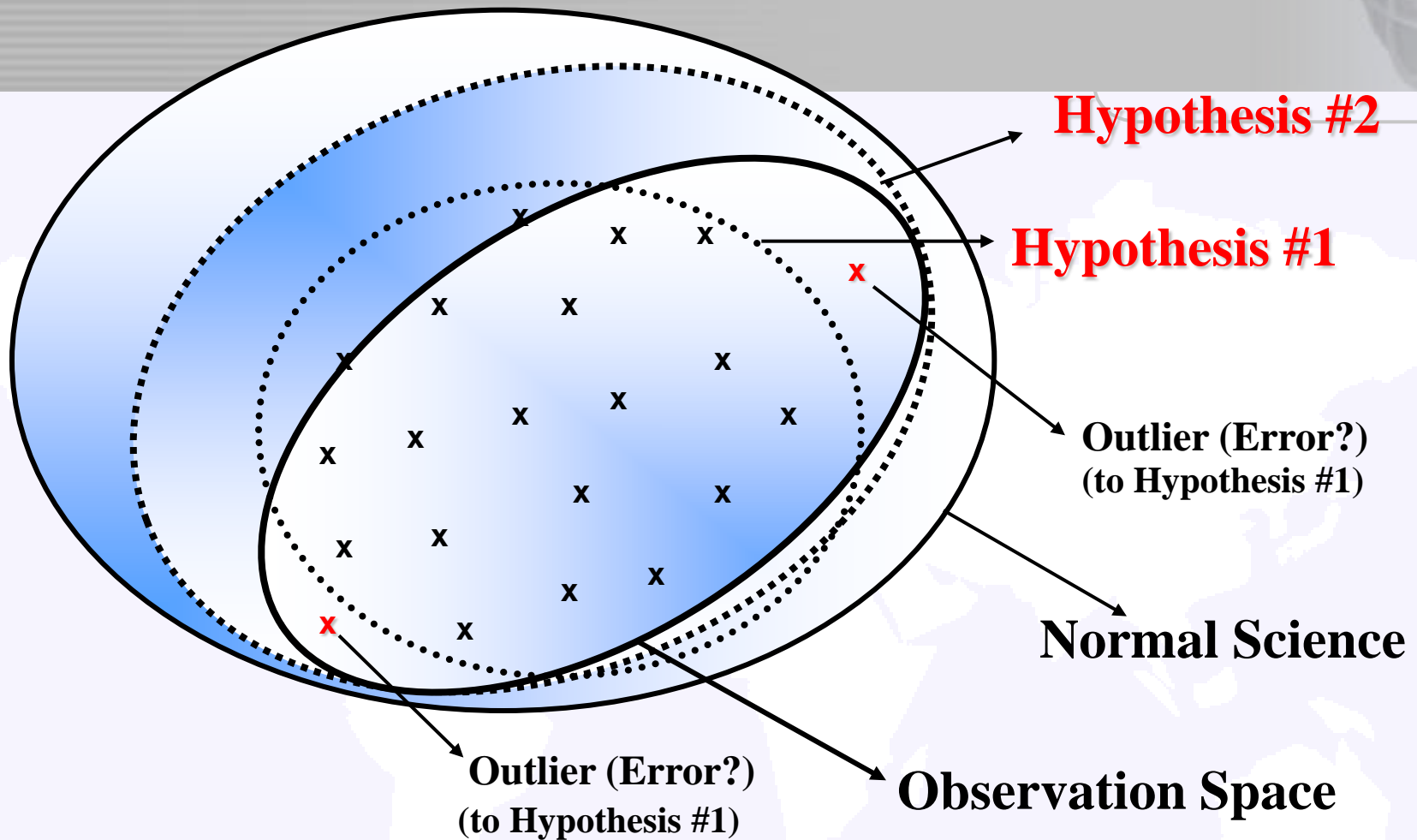
***The Structure of Scientific
Revolutions (3rd Edition),
University of Chicago Press,
2012.***



***Exceptions,
Singletons
and Statistical Errors***
***- A New Hypothesis vs. a New
Paradigm***

Experimental Error vs. Hypothesis





Alternative Hypothesis and Observed Data

Expected Return from R & D

$$E(\$) = \sum_{i=1}^{\infty} R_i(\$) \cdot P(S_i / C = i) \cdot P(C = i)$$

E (\$) = Expected Overall Return (\$)

R_i (\$) = Reward with Choice **C = i**

P (C=i) = Prob. of making Choice **C = i**

P (S_i/C=i) = Conditional prob. of success given **C = i**

P (C = i) is determined by "Research Hypothesis"

P (S_i/C=i) is determined to a degree by "Serendipity"



“ Those who rise best to the challenge will be those who think most strategically and act most proactively ”

– Philippe Guy, The Boston Consulting Group

Creativity, Efficiency, and Excellency

*“Organizing Genius –The
Secrets of Creative
Collaboration”*

*Warren Bennis and Patricia Ward
Biederman, Perseus Books, 1997.*

Which is my lucky way?

Do I have a (research) hypothesis?



Thank you!

